A SKIAGRAPHIC STUDY OF THE NORMAL MEMBRAL EPIPHYSES AT THE THIRTEENTH YEAR.

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FOREWORD.

My object in making these skiagraphic studies of the normal membral epiphyses is to show what the X-ray can do for us in the investigation of the development and growth of the bones, and to furnish an aid in the interpretation of the X-ray findings when these parts and their relationships are altered by disease or trauma. Before we can interpret correctly the fluoroscopic image or the skiagraph of the fractured bone or separated epiphysis, we should have before us a skia-

PLATE XIII.

A skiagraph of the carpus and the lower epiphyses of the ulna and radius from the palmar surface, somewhat magnified, to show what can be done in producing enlarged figures for anatomical study. While, of course, the outlines are not so sharp, the detail of the spongy tissue of the bones is more evident than in the skiagraph of normal size. This method seems to me worthy of further trial in the preparation of anatomical charts for the lecture-room and the laboratory. Only by frozen section can be obtained the absolutely normal relations of the bones as here depicted; no drawings from dried or wet specimens could so accurately outline for us the epiphysis, shaft, and intervening cartilage. In the radius at this age we can see the beginning bony spiculæ bridging the cartilaginous interval, though some time must yet elapse before firm bony union is accomplished.

The relation of trapezium and trapezoid to the metacarpal of the thumb is well brought out.

Compare this figure with the ones given in Gray of the carpal bones, and its superiority becomes at once evident. In the former the bones are spaced as they really are, in the latter they are united as in the prepared skeleton.

graphic picture of the normal parts and in their normal relations. We cannot then go astray, and, moreover, the eye will be prepared to take in much which it would otherwise fail to see.

I trust, too, that these plates will prove useful in conjunction with the work of Mr. John Poland, F.R.C.S., on "Traumatic Separation of the Epiphyses," a work of great research and great learning, and from which I have drawn largely in my brief descriptions of the development of the epiphyses.

The skiagraphs are all from one subject, a mulatto boy of thirteen years; they are practically untouched, and represent simply the prints on "velox" paper of carefully made negatives.

The X-ray will prove to be a valuable aid in the study of many points in normal anatomy. The bone relationships in joints, the various joint movements, and the different steps in bone development can all be studied in a striking way by the X-ray. I have already attempted to show the normal movements of the carpal bones and wrist by this new method,[1] and I shall now attempt to show what can be done in a study of the normal membral epiphyses at an age nearly midway between birth and perfected adult growth.

PLATE I.

Skiagraph of right shoulder from behind, showing body and spine of scapula, coracoid process, and glenoid cavity, and the entire epiphysis of the humerus, comprising the head and the greater and lesser tuberosities. The bicipital groove can be made out. Faint evidence of beginning ossification in proximal centre of acromion, the rest of this process cartilaginous; distal end of clavicle still partly cartilaginous; distal end of coracoid cartilaginous.

Exposure, four minutes.

I have been prompted to do this work from the great impetus given to the study of fractures and traumatic separations of the epiphyses by the discovery of Röntgen, a discovery which makes possible and easy an absolutely correct diagnosis where previously uncertainty and error outweighed definite knowledge. To intelligently interpret the X-ray find-

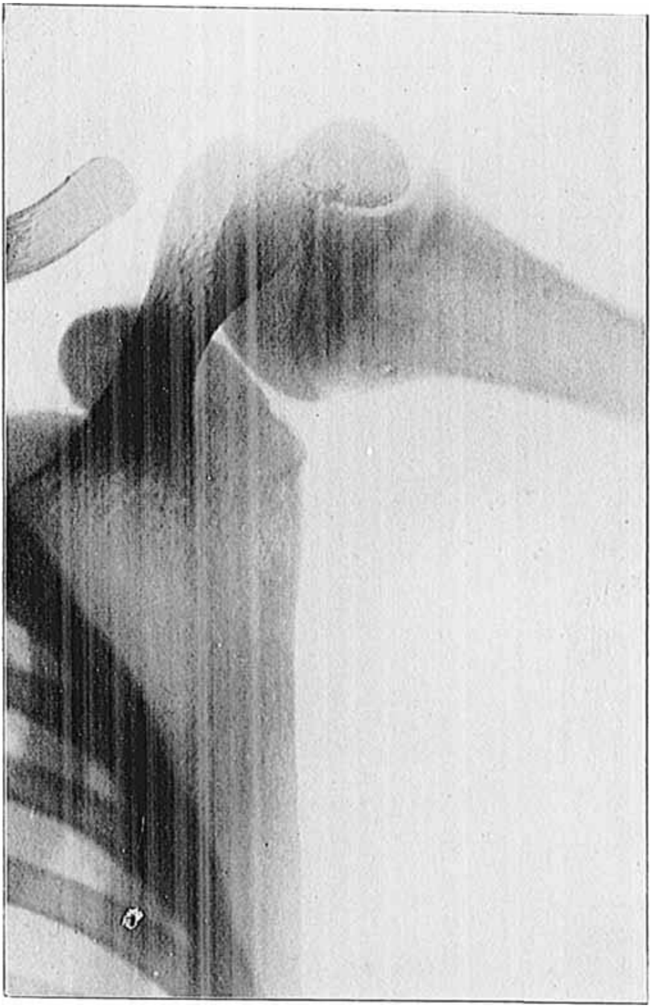

PLATE I.

ings in traumatic separations of the epiphyses, we should have before us good skiagraphs of the normal joints during the formative period. With these as a basis for comparison, it will be easy to recognize any deviation from the normal, be it from trauma or from disease.

Germany, which still leads in all that pertains to the X-ray, has already begun an " Atlas der Normalen und Pathologischen Anatomie in Typischen Röntgenbilder," of which two parts have already appeared, one dealing with the process of ossification and the development of the fœtal skeleton, and one with the congenital malformations of the upper extremity.

Mr. John Poland, F.R.C.S., has published a "Skiagraphic Atlas showing the Development of the Bones of the Wrist and Hand" (London, Smith, Elder & Co., 1898), which shows how instructive this comparative X-ray study is. Even in the two years which have gone by since the publication of that work great progress has been made in X-ray technique, so that we can now get skiagraphs which bring out most beautifully the internal structure of the bones and make even plainer the smaller centres of ossification. This will be shown in the skiagraphs illustrating this work.

Mr. Poland has put the profession in much greater debt to him by the publication of his great work on the traumatic separation of the epiphyses;[2] an encyclopædic work, the result of many years of rich experience and careful study. The many references to the complete literature of the subject bear witness to great labor and judgment, and the many illustrations and skiagraphs bring the book well up to date. A skiagraphic atlas of the normal epiphyses will add, I trust, to the value of this work, and I have undertaken it with this object in view. In my short descriptions of the development of the different epiphyses, I have drawn largely from Mr. Poland's work, being well assured of its accuracy. The most casual survey of medical periodical literature shows how many are working in this new and fascinating field, and the secret of it all is the satisfaction and the fascination of making absolutely correct diagnoses in cases which heretofore left much in doubt if not in total obscurity.[3]

The X-ray is most wonderfully adapted to this work, cartilage being practically transparent to the ray, the division line between epiphysis and shaft is clearly brought out, and the sensitiveness of the ray to the presence of any earthy salts in the cartilage enables us to show the very earliest beginnings of ossification. By this method, then, we can go over again the entire field of bone development, and it will undoubtedly definitely settle some mooted points and change some of our data as put down in the standard text-books. Further investigation by this method will show, I believe, that ossification in the various bones is usually somewhat earlier than previous research has determined, for the X-ray will show the shadow of the earthy salts before the knife and the naked eye can detect them. In the subject of my experiments I have found almost all the epiphyses further developed than the text-books would indicate, and certain others started which, according to the authorities, had no right of existence. The skiagraphs are all from the one subject, a light mulatto boy, born on August 29, 1887, so that he will not be thirteen years old till this coming August, 1900. Thus the skiagraphs were taken in the last three months completing his thirteen years. His height in his stockings is four feet six inches, and his weight is seventy-five pounds. He is a healthy, muscular boy,

PLATE II.

Left elbow from behind, coronal view, showing all the epiphyses at the joint. Wedge-shaped lower epiphysis of the humerus comprising the capitellum and trochlea; very faint indication of beginning ossification of external epicondyle.

Epiphysis of internal epicondyle well developed; olecranon fossa very distinct.

Epiphysial head of radius.

Epiphysis of olecranon; the main body of the olecranon with the outlines of the greater and lesser sigmoid cavities all very distinct.

The spongy texture of the bone well brought out.

Exposure, three minutes.

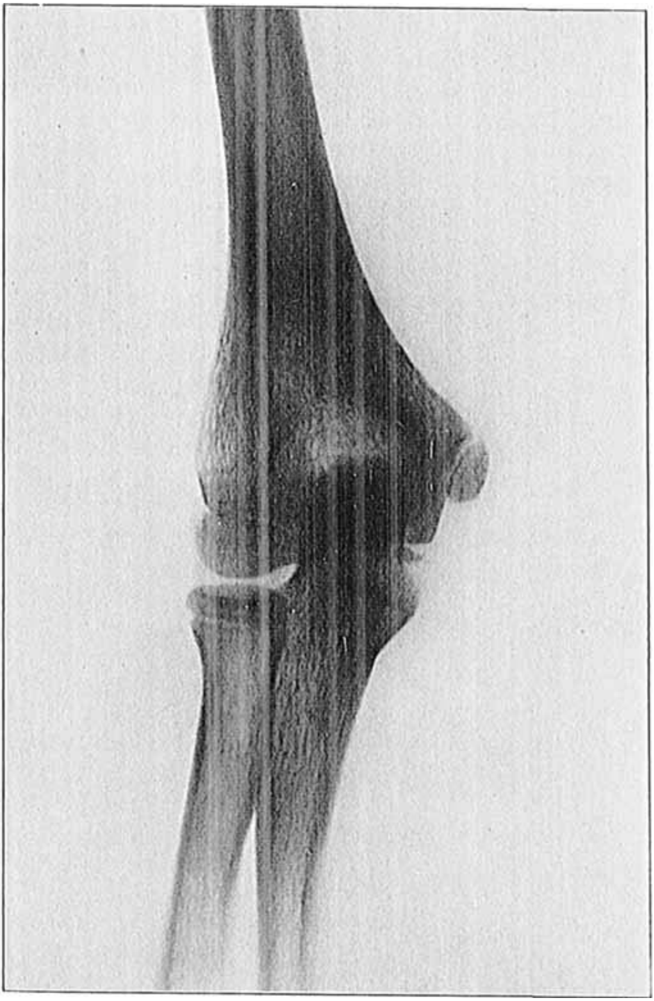

PLATE II.

and the skiagraphs will show good bony development for his age.

In my earlier X-ray work I intrusted the developing and printing of the plates to a professional photographer; but I soon found that, unless I had him entirely at my beck and call, it was impossible to do any systematic work. There were certain differences in photographic technique to produce prints from the negatives, such, at any rate, as I conceived they should be, that he had much to learn, just as I had to learn the entire process, having had no previous knowledge or experience in photographic work. I found that what the professional would regard as a fine negative did not always give a satisfactory print, one that gave the deep and essential details without the superficial ones and the flesh. Thus I found that every negative had to be intensified just as regularly as the plate was developed and fixed. There were further difficulties to be overcome in printing which did not exist in ordinary photographic work. This is not the place to give the details of this work, and I shall describe them in a separate paper. I shall simply state that my X-ray outfit is composed of a Willyoung fifteen-inch spark coil energized by thirteen storage cells of chloride accumulator type D. 5, with a Queen independent vibrator. I have used entirely the Queen self-regulating X-ray tube, a marvel of ingenuity and efficiency. I have used the Carbutt X-ray plates as well as the Seed's extra-rapid plate, No. 27. This latter plate is cheaper and just as good as the Carbutt, and I use it now entirely. I have found that the Eastman hydrochinon developing powders are as good as, perhaps better than, any other developer, and very handy. I use a chrome-alum fixing bath as given by Carbutt and Carbutt's formula for the intensifier. For a printing paper I use solely the "carbon matt velox," which has many advantages over all other printing papers, at least to produce prints as I conceive they should be.

These skiagraphs are very different from any I have seen. I have attempted to bring out the bones on a perfectly white background and with all the detail possible. They show the normal joints and epiphyses at a stage of development sufficiently advanced to bring out all the epiphyses and the bony structure of the joints. I hope to demonstrate how clearly the X-ray can show us these parts and with the very texture of the bone in many cases. If the print could be made to equal the negative in the minuter details the skiagraph would be better than the photograph of the bone itself, for the negative gives us the internal structure, and you get, moreover, a depth and a perspective to your picture. One can but marvel at these shadows, for they are both shadow and substance.

With these normal skiagraphic pictures before us, it will be easy to compare the abnormal views we get when disease or trauma alters the parts and their relations. To interpret properly the skiagraph of a fracture or a dislocation, it is necessary that we have a picture before us of the normal parts *and in their relations as the X-ray shadows show them.* There has been much written about the deceptions of the X-ray tending to depreciate the value of this method. In the same spirit the revelations of the microscope or any other delicate instrument could be depreciated. In fact, to the unpractised eye the microscope is much more liable to lead one astray, for the proper conditions are more difficult to learn, and a much longer practice is necessary to enable one to interpret correctly the findings. The case with the X-ray is simpler, and with a proper understanding of the nature of these shadows cast upon the

PLATE III.

Skiagraph of elbow from inner side, sagittal view, showing all the epiphyses of the joint. Capitellum and trochlea of the humeral epiphysis very prominent, especially the former. The compact bone of the shaft meeting at the thin partition which separates the olecranon fossa from the anterior surface, and expanding into the circular ridge of the trochlea, so characteristic of sagittal sections of the humerus, well shown. Osseous granules at the inner and small end of the epiphysial wedge. Epiphysis of internal epicondyle.

Epiphysial head of radius.

Epiphysis of olecranon.

Greater and lesser sigmoid cavities and coronoid process.

Exposure, three minutes.

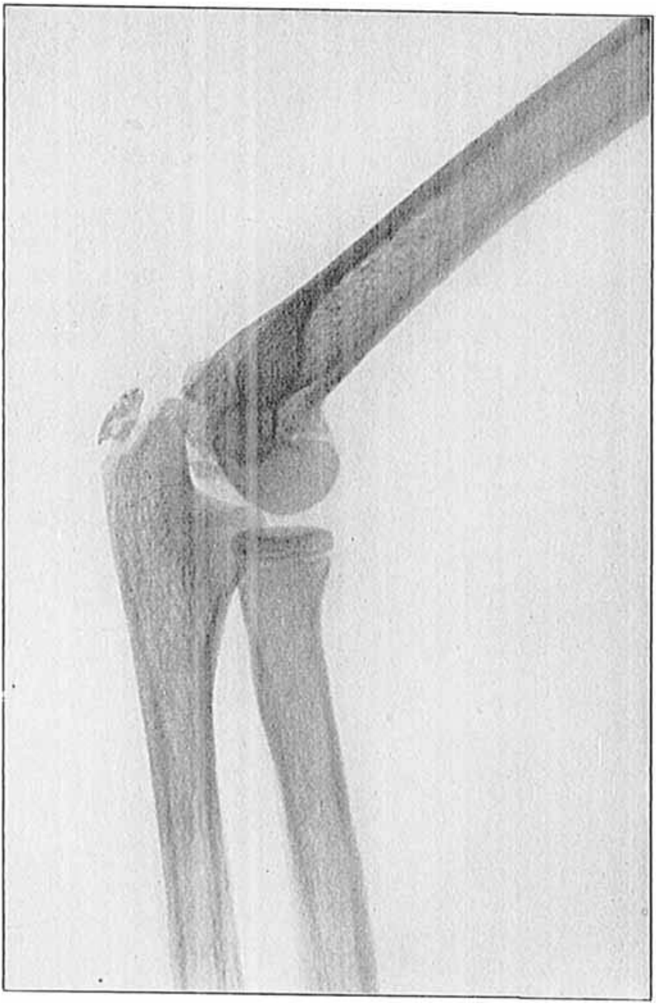

PLATE III.

fluoroscopic screen or the photographic plate, it soon becomes easy to take in the pictures at a glance. The very fact that we are dealing with shadows should show us that more than one point of view is necessary to judge correctly. A shadow has but two dimensions, and a second shadow at right angles to the first becomes necessary to give us the three dimensions. This is strikingly shown in certain cases of fracture where from one point of view the apposition of the broken bones seems perfect, while from a view at right angles to the first the displacement of the broken ends becomes evident. In a fine negative, as I have said, we get more than the mere two dimensional shadow; being a translucent shadow, we really get depth and perspective to our picture, and in some cases this is most beautifully shown.

When the proper conditions are known, the X-ray cannot deceive; its revelations are infallible. Before the pathologist can interpret his microscopic findings, he must know his normal histology. So with the skiagrapher, he must know and have before him the normal skiagraph before he can interpret properly the abnormal.

SHOULDER.

Plate I shows the right shoulder from behind, the scapula resting on the plate. We have here three bones to consider. The clavicle develops from two centres, one for the shaft and one for the sternal end, having, therefore, but one epiphysis. The centre for the shaft appears very early, earlier than any other bone, according to Béclard, as early as the thirtieth day. Strange to say, the centre for the epiphysis does not appear before the eighteenth or twentieth year and unites with the shaft at the twenty-fifth year. This epiphysis does not concern us here.

In our subject, the acromial end of the bone is still partly cartilaginous. The entire bone being small and some distance from the plate gives but a faint shadow. In the adult with the bone fully ossified it is better shown. In the negative it is much better defined. To have brought it out more distinctly in the print, the other bones of the shoulder would have been too dark for any details. The scapula develops from seven centres, one for the body appearing about the eighth week, two for the coracoid process, two for the acromion, one for the vertebral border, and one for the inferior angle. The last two do not concern us here. The centre for the coracoid proper appears early, about the first year; while the centre for the subcoracoid bone does not appear till about the seventeenth year. Of the two centres of the acromion, the one at the base appears about the fifteenth year and the distal one a year later. According to Poland, the glenoid cavity consists of four parts, that of the body of the scapula, the internal portion of the coracoid, the subcoracoid bone, and a thin epiphysial plate at the margin of the glenoid, thicker at the edge and thin towards the centre. These all joining and forming the glenoid cavity proper from the twentieth to the twenty-fifth year.[4]

PLATE IV.

Skiagraph of the lower epiphyses of radius and ulna with carpus, from the dorsal surface. Somewhat enlarged.

Epiphysis of ulna with rudimentary styloid process.

Epiphysis of radius.

Proximal epiphysis of metacarpal of thumb and epiphysis of its first phalangeal bone.

Exposure, one minute.

Examining the skiagraph, we find a well-developed body and spine and an evident beginning ossification in the proximal end of the acromion, though Gray puts this two years later, and Poland one year later, or at the fourteenth year. The spine comes out very sharp with radiations at the base out into the body of the scapula. The short stubby coracoid is well in evidence; it is evidently already joined to the body of the bone; the apex is still cartilaginous. The acromion proper is still largely cartilaginous, though we have faint indications of beginning ossification in the proximal end, more plainly shown in the negative. The glenoid cavity appears still immature. At the outer edge we begin to see evidence of the formation of a rim. Altogether, at this age, the scapula is fairly well developed.

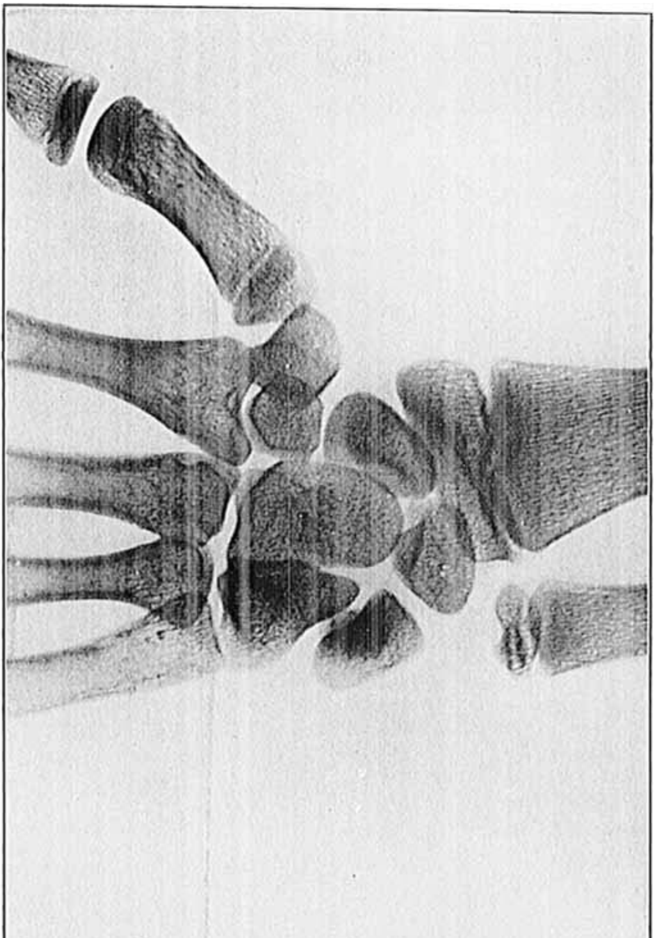

PLATE IV.

According to Poland, osseous granules appear in the upper epiphysis of the humerus about the middle of the first year. "About the end of the first year these granules begin to group themselves into three centres, that for the head appearing first at the beginning of the second year, and that for the greater tuberosity during the third. The centre for the lesser tuberosity is not well marked until the end of the fourth year, at times as late as the end of the fifth. At this period these three centres are pretty accurately divided from each other by the anatomical neck and the bicipital groove; they begin to blend with each other about the sixth year (some anatomists state from the third to the fifth year), the lesser tuberosity joining first by its upper part with the head and greater tuberosity, and the latter being still separated from the head by a layer of cartilage. It is therefore possible to have a separation of the epiphysis of the head alone.

"Somewhat later the greater tuberosity blends with the upper part of head, and the large upper epiphysis is fully formed.[5]

"The cuplike epiphysis rests with its concavity upon the pointed concave end of the diaphysis. The cone-shaped end of the diaphysis only develops as age increases; in infancy it is almost flat, and afterwards becomes slightly convex."[6]

In the skiagraph the completed epiphysis comes out clearly separated from the shaft. The centre of the greater tuberosity appears faint from being viewed free from the shaft, and ossification not being complete. The cone-shaped end of the diaphysis is beautifully shown. The heavy shadow below the line of demarcation shows us the centre of the lesser tuberosity viewed through the cone-shaped portion of the shaft. We can see here how the epiphysis overlaps the shaft like a cup. Below this again we see the fainter line of demarcation of that portion of the bone away from the plate. Thus the three divisions of the epiphysis are brought out, the two lines marking out for us the anatomical and surgical necks. The skiagraph compares very favorably with the drawings of the parts themselves.

ELBOW.

The epiphysis of the lower end of the humerus is the most difficult to understand in its development, and about which there is still some discrepancy existing among authorities. The elbow-joint, moreover, is perhaps the most important one surgically, especially in the traumatic separation of its epiphyses, and from fractures extending into the joint. Nowhere can I find a more exhaustive study of this joint than in the work of Mr. Poland, and I shall make use largely of his descriptions.

Up to the third year this epiphysis is almost entirely cartilaginous, barring a few osseous granules in the capitellum. It is at the end of the third year only that the nucleus of this portion is well advanced. By the end of the sixth year ossification is well advanced, extending inward, and forming the outer half of the trochlear surface, but it remains till the fifteenth or sixteenth year free from the shaft.

PLATE V.

Skiagraph of the lower epiphyses of radius and ulna with carpus, from the palmar surface.

Exposure, one minute. Somewhat enlarged.

"By the sixteenth year the whole of this portion of the articular surface is entirely osseous, and forms a hemispherical mass, with its convex surface below and in front towards the cup of the radius, whilst its upper slightly excavated surface is presented towards the end of the diaphysis." [7]

"In the cartilage of the *trochlea* an osseous centre next becomes visible towards the projecting part or inner lip of this surface. Sometimes there are two, the second smaller one being more external and soon blending with the larger. This appears between the eleventh and twelfth years, at times a little later." [8]

The last to appear at the thirteenth or fourteenth year is the nucleus for the outer epicondyle, uniting finally about the sixteenth year with the epiphysis proper.

"About the fifteenth or sixteenth year the two portions

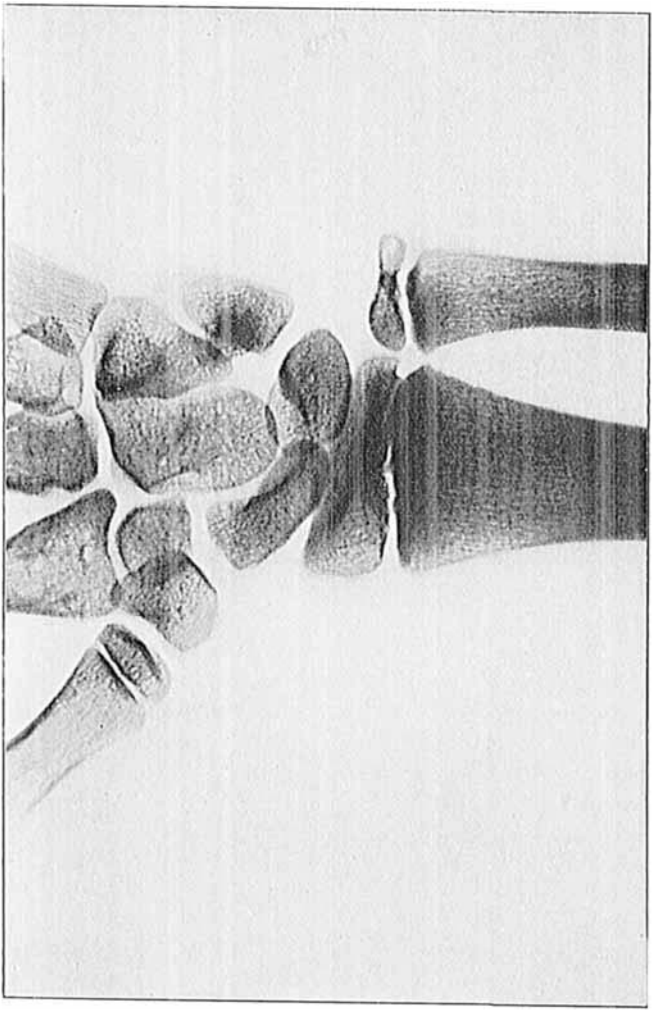

PLATE V.

of the articular surface formed by the capitellum and trochlea blend together (commencing at the groove of the trochlear surface) and produce one articular surface; the external epicondyle is then joined on. These three portions form by their junction the lower epiphysis of the humerus, which does not include the internal epicondyle. This is relatively to the developing shaft much thinner than the cartilaginous lower end of the humerus of infancy, consequently the epiphysial line of junction is much nearer to the articular cavity than in the earlier period of life.

"The internal epicondyle forms a distinct epiphysis by the downward growth of the diaphysis separating it from the rest of the end of the bone, which usually unites with the diaphysis without blending with the trochlea. This junction is effected from the eighteenth to the twentieth year, but as late as the twenty-fifth year traces of the line of junction may still be seen.

"The lower end of the bone decreases relatively in size as childhood advances."[9]

At the twelfth year the olecranon and coronoid fossæ are formed almost entirely in the shaft, while in infancy the epiphysis completes the lower part of the olecranon fossa. At birth the epiphysial line is almost transverse, and remains for some time completely above the epicondyles. The diaphysis thickens at each side to form the lateral projections, and growing downward forms the whole of the olecranon fossa, but especially at the inner side towards the internal epicondyle, apparently at the expense of the epiphysis. The shaft penetrates, as it were, the trochlea, thus supporting and strengthening the epiphysis. However, on the outer side, the epiphysis remains much thicker,—nearly double the size of the trochlea, and is not invaded by the diaphysis.

At thirteen years the epiphysial line runs obliquely downward and inward, the epiphysis on the inner side being thin, and limited precisely by the cartilage-clad area in front and behind. On the inner side it rises slightly towards the internal epicondyle, still almost separated from the growing diaphysis.

The external epicondyle is rarely isolated in the same manner from the epiphysis.

"The epiphysial line of the epiphysis proper, comprising the external epicondyle, the capitellum, and the trochlea, is therefore very obliquely placed if we draw a transverse line uniting the apices of the two epicondyles. The plane of the articular surface likewise makes an acute angle inward with the same transverse line. On the outer side the epiphysial line terminates above the external epicondyle, on the inner side below the internal epicondyle."[10]

The epiphysis of the internal epicondyle is firmly united to the shaft by the seventeenth year. After this the growth in length of the humerus is arrested so far as the lower extremity is concerned, but is carried on by the epiphysis of the upper extremity till fully formed.

Mr. Poland has most minutely described the entire process, and no book to my knowledge gives one such a clear idea of the anatomy of this important joint and the different steps in its development. I am indebted to him for all the facts in the case. And where I have not used quotation marks, I have only slightly changed his wording and sequence in order to condense somewhat his minute description. This will help us to understand the skiagraphs, and it will be seen how beautifully the X-ray findings bear him out, and were we to skiagraph the elbow for each year of its development, the whole developmental process would be studied about as well as on the cadaver.

PLATE VI.

Skiagraph of hand from the dorsal surface, showing the epiphyses of all the bones of the fingers, with the internal structure of the bone.

Exposure, one minute.

Plate II gives an antero-posterior or coronal view of the elbow, and brings out clearly the epiphysial development of the joint at this age. The internal epicondyle is well developed and entirely independent of the humeral epiphysis proper. It has become an apophysis of the humerus, and we can readily

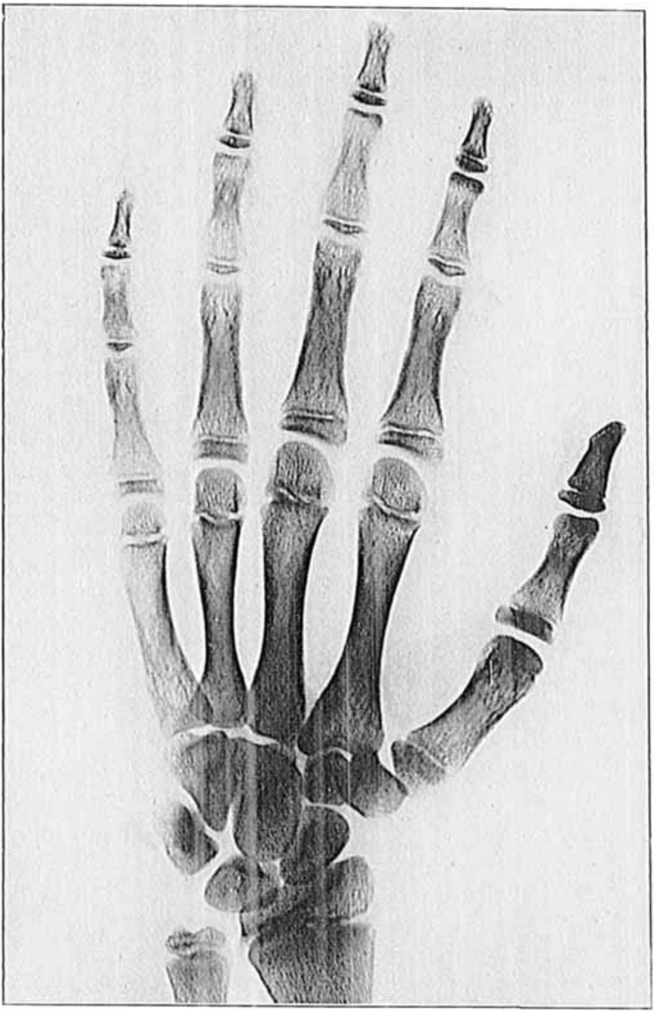

PLATE VI.

see how the shaft has grown down towards the joint on the inner side, so well described for us by Mr. Poland, changing the original transverse epiphysial line to an oblique one, inward and downward. At first glance the epiphysis seems reduced to a narrow wedge, but a closer inspection will show a second fainter epiphysial line seven millimetres above the first, showing us the oblique epiphysial surface overlapping the shaft anteriorly and seen through its thin lower end. We thus get an absolutely correct shadow of this epiphysis which we can measure accurately, the bone coming so close to the photographic plate that there is practically no enlargement. As the skiagraph was taken with the posterior surface on the plate, the lower and more distinct epiphysial line is posterior and the upper is anterior, the entire epiphysis still preserving its characteristic wedge-shape. The capitellum is well shown and its relation to the head of the radius. We have a faint trace of the nucleus for the external epicondyle. The trochlea is not evident in this view. We can see beautifully outlined the olecranon fossa, and that it has become quite entirely a part of the diaphysis, a feature already mentioned. The internal end of the epiphysial wedge terminates in almost a sharp point, showing how ossification has well advanced to the inner trochlear border.

Plate III gives a side or sagittal view of the joint, bringing out the other features of the epiphysis to complete the picture. This view is taken with the inner side of the joint on the plate, but is, however, not accurately transverse, but somewhat obliquely placed, the obliquity being inward and backward. The prominent capitellum is well shown still separate from the shaft, and somewhat enlarged by being some distance from the plate. It should ever be borne in mind that the further the object is from the plate the larger the shadow as well as fainter. It is only when the object is directly on the plate that the shadow and the object correspond. The trochlea is represented by the two curved lines and the small shadow lying apparently in the joint, the external border or lip being represented by the smaller and darker curve, almost a complete circle, and so characteristic in sagittal sections of the lower end of the humerus. The internal border or lip is represented by the larger and fainter curve, the smaller shadow below being the most internal point of the epiphysial wedge ultimately helping to form the prominent internal border of the trochlea, and corresponding to the point of bone just within the internal border of the olecranon shown in the coronal view in Plate II.

The internal epicondyle is well differentiated, though not so strikingly shown as in the other view.

A study of these two views gives us a very complete picture of this intricate epiphysis. An even more complete study of this joint could be made by taking one or more skiagraphs at somewhat different angles. By the X-ray we should be able to diagnose easily a traumatic separation complete or partial of this lower epiphysis of the humerus, provided, of course, the skiagraph is a good one. I have seen some poor ones published where it was very difficult or quite impossible to diagnose exactly the injury sustained.

PLATE VII.

Skiagraph of the hip from behind with the foot everted, the thigh abducted, and the greater trochanter as close to the plate as possible, showing the epiphyses of the greater and lesser trochanters and the epiphysial line of the head of the femur.

Epiphysial junction of ilium and pubic bones with the acetabulum all very distinct.

Exposure eight minutes. By using a fluorescent screen, the exposure is one and one-quarter minutes.

The ulna develops by three centres, one for the shaft appearing about the fifth week, one for the lower extremity, appearing about the fourth year, and one for the end of the olecranon, appearing about the tenth year.

The upper end of the ulna cartilaginous for the first few years includes the upper half of the olecranon, its anterior joint surface, and the coronoid process. As the shaft ossifies and grows upward, this cartilaginous portion is gradually reduced, until by the eighth year the epiphysis of the olecranon

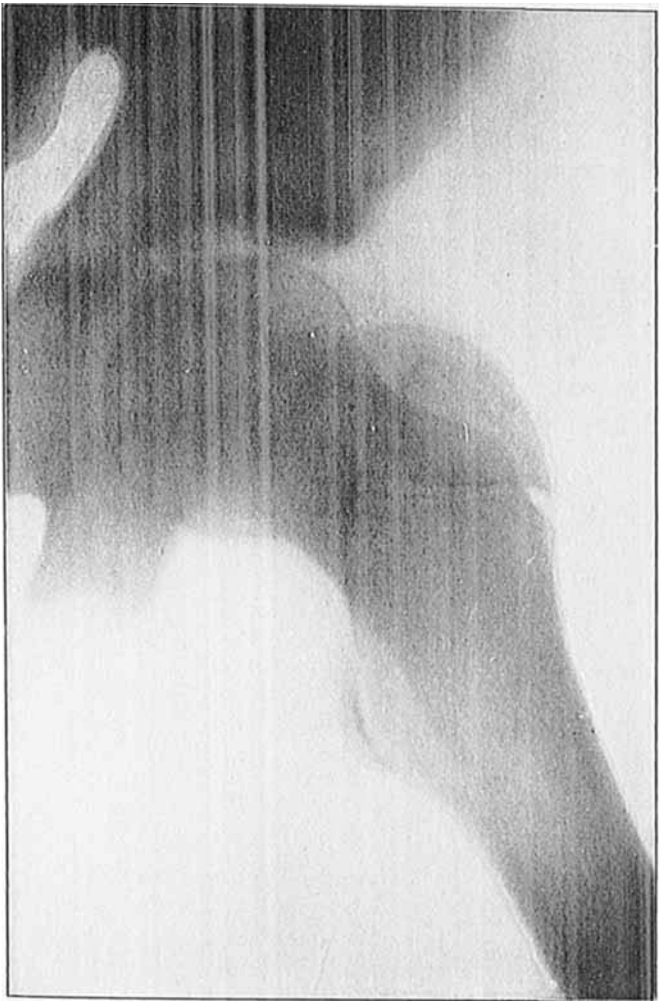

PLATE VII.

alone remains. The olecranon, therefore, is almost entirely a part of the shaft. As late as the tenth year, or later, the tip of the coronoid process may still be found cartilaginous. It disappears during the growth and development of the coronoid without undergoing any separate ossification.[11]

An ossific centre appears at the end of the cartilaginous olecranon about the tenth year, joining the shaft and forming a completely ossified olecranon at the fifteenth or sixteenth year.

Mr. Poland describes a second nucleus, often seen as early as the fifth year, forming "the outer side of the upper part of the sigmoid cavity and the tip or beak of the olecranon and a small portion of the inner side of the sigmoid cavity." [12]

In Plate III, the sagittal view of the joint, the skiagraph brings out very clearly the epiphysis of the olecranon. It shows, also, how well advanced is the ossification of the sigmoid cavity; and in the lighter shading one can see clearly the outlines of the lesser sigmoid cavity with the play of the head of the radius in it. The smoothly rounded coronoid process shows that complete ossification here is still lacking, for in the adult coronoid process there is quite a sharp point beautifully brought out by the X-ray. The epiphysis of the olecranon can also be seen in Plate II, the coronal section, though not so clearly. Both plates show us plainly how well advanced ossification is in the olecranon, and how largely it is but a part of the shaft of the bone, formed by the upward growth of the diaphysis.

The development of the radius follows the same general schema, one centre for the shaft, appearing about the fifth week; the centre for the lower extremity about the second year and joining the shaft about the twentieth; and the centre for the head about the fifth year and joining the shaft at puberty.

According to Poland, the centre of the head appears about the sixth year, is completely ossified at the sixteenth year, and joins the shaft early in the seventeenth year, at times a little later.[13]

"Rambaud and Renault describe a number of accessory osseous nuclei which are placed in a remarkable manner around the principal central plate, and when joined together and to the central portion form the characteristic concavity of the epiphysis."[14]

The epiphysial head of the bone is beautifully shown in the two skiagraphic views, still ununited to the shaft. That ossification is still incomplete is evident from the fact that there is no apparent neck to the bone, and that the head barely projects beyond the shaft, so different from the adult bone, when there is a clearly defined neck and where the head projects from two to four millimetres beyond this neck all around.

It will be noticed that there is practically no bicipital tuberosity at this age. Mr. Poland describes a small epiphysial plate developed about the sixteenth year to form the bicipital tuberosity and which rapidly joins the shaft. This bicipital tuberosity is of course distinctly shown by the X-ray in the adult radius.

PLATE VIII.

Skiagraph of knee from behind, coronal view, showing lower epiphysis of the femur and the upper epiphyses of the tibia and fibula.

The sinuous line of the femoral epiphysis with the two condyles and the intercondyloid notch very distinct.

Faint shadow of the patella.

The upper epiphysis of tibia with its superior articular surface, its spine and the tubercle on each side.

The upper epiphyses of fibula.

Exposure, four minutes.

WRIST.

The two epiphyses of the wrist are easily seen and studied by the X-ray, for the joint lends itself most favorably to fluoroscopic examination, as I have attempted to show in my paper on the normal movements of the carpal bones and wrist.

According to Gray the centre for the lower epiphysis of the radius appears about the second year, the centre for the ulnar epiphysis about the fourth year; they join their respective shafts about the twentieth year. Mr. Poland, in his

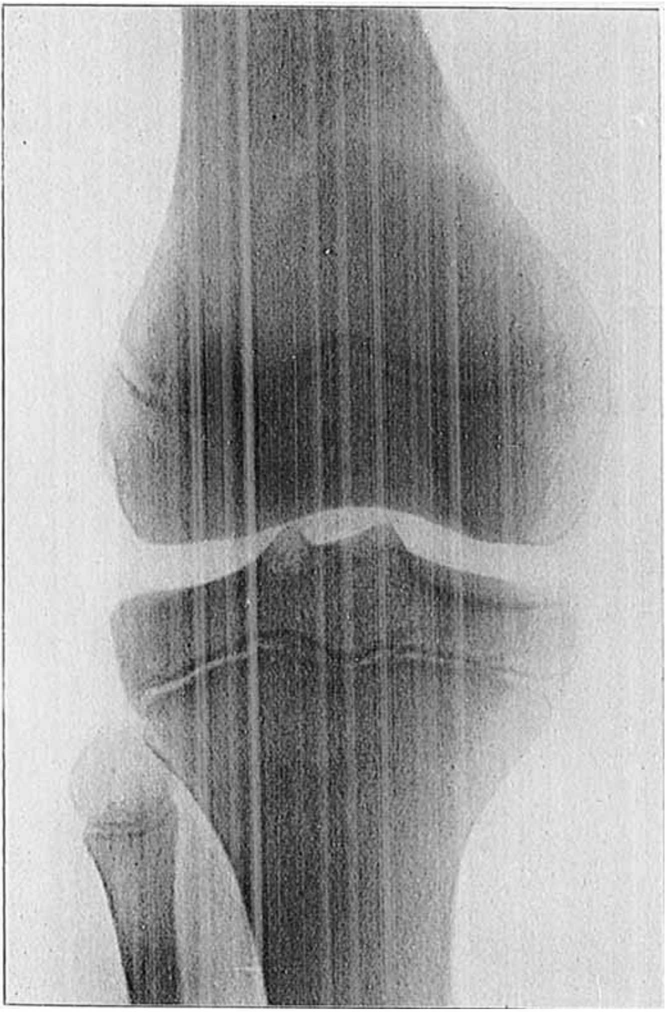

PLATE VIII.

" Skiagraphic Atlas showing the Development of the Bones of the Wrist and Hand," shows us well the skiagraphic findings of these two epiphyses from the first year up to the seventeenth year. He shows us the hand of an infant just one year old where ossification in the radial epiphysis is already well started, while in his skiagraph for the sixth year the osseous nucleus for the ulnar epiphysis has but just appeared. That the radial epiphysis should appear first is what we should have expected, remembering that the radius is the most important and largest bone at the wrist, being directly concerned in the joint, while the ulna is only indirectly so. These two bones reverse their relative importance at elbow and wrist; at the elbow the ulna is the important bone and the radius but the hanger-on, while at the wrist the ulna has become the hanger-on.

In his larger work, Mr. Poland writes, "About the fourth, fifth, or sixth year, the chief nuclei of the carpal extremity appear towards the centre of the head and base of the styloid process. These lie close together, and soon blend, forming an osseous plate which extends downward on the inner side into the styloid process. This process is formed principally from this centre, but an additional centre is sometimes seen at the summit, appearing about the twelfth year, and joining the rest of the osseous epiphysis three or four years later." [15]

Of the radial epiphysis, he writes, " Towards the end of the second year the osseous nucleus of the lower epiphysis of the radius appears above the scaphoid facet." [16]

He alludes to this discrepancy in his description of the first skiagraph in his " Atlas." Certain it is that the X-ray will modify many statements that appear in our standard anatomical works relative to the centres of ossification.

In our own skiagraphs of the wrist and hand the epiphyses are well brought out, showing, however, certain differences, whether taken from the dorsal or palmar aspects.

In Plate V the skiagraph is taken from the dorsal side, and in Plate IV from the palmar. We get a narrower shadow of both ulnar shaft and epiphysis from the dorsal surface, and you get, besides, an evident beginning styloid process which you do not get from the palmar surface, the rudimentary styloid process being nearer the plate in this case. You can make out an osseous ring at the base of the styloid, the double shadow of its base and epiphysis proper.

Slight differences can be made out in the carpal bones depending upon the surface exposed to the plate, too slight to be of any practical importance. The differences in the radial epiphysis are also practically insignificant. In this case there are two bony projections between shaft and epiphysis, indicating that bony union of the two has begun, though the epiphysis itself is still immature. Undoubtedly, a certain growth and development of the epiphysis must go on even after union to the shaft has taken place.

PLATE IX.

Skiagraph of knee from the inner side, showing the patella, the lower epiphysis of the femur, and the upper epiphyses of the tibia and fibula. The stronger and sharper shadow shows the outline of the condyle next to the plate; the fainter shadow the condyle away from the plate.

The upper epiphysis of the tibia showing the spine and tubercle on its articular surface, and the double epiphysial line from the epiphyses forming an angle with the line of the X-ray. Separate centre for the tubercle of the tibia.

Epiphysis of fibula showing through the tibia.

Exposure, four minutes.

The enlarged skiagraph of the carpus in Plate XIII shows us the carpal design drawn in strong lines.

HAND.

The hand lends itself so marvellously to the X-ray that we can expect to get here all the bony details it is possible for the X-ray to bring out, and the skiagraph of Plate VI shows us the substance as well as the shadow. Such a figure is preferable to that given by Gray, for we have all the fine internal structure. Also the figure showing the development of the hand could with advantage give way to a fine skiagraph of the parts. According to Gray, the shafts of all the metacarpal

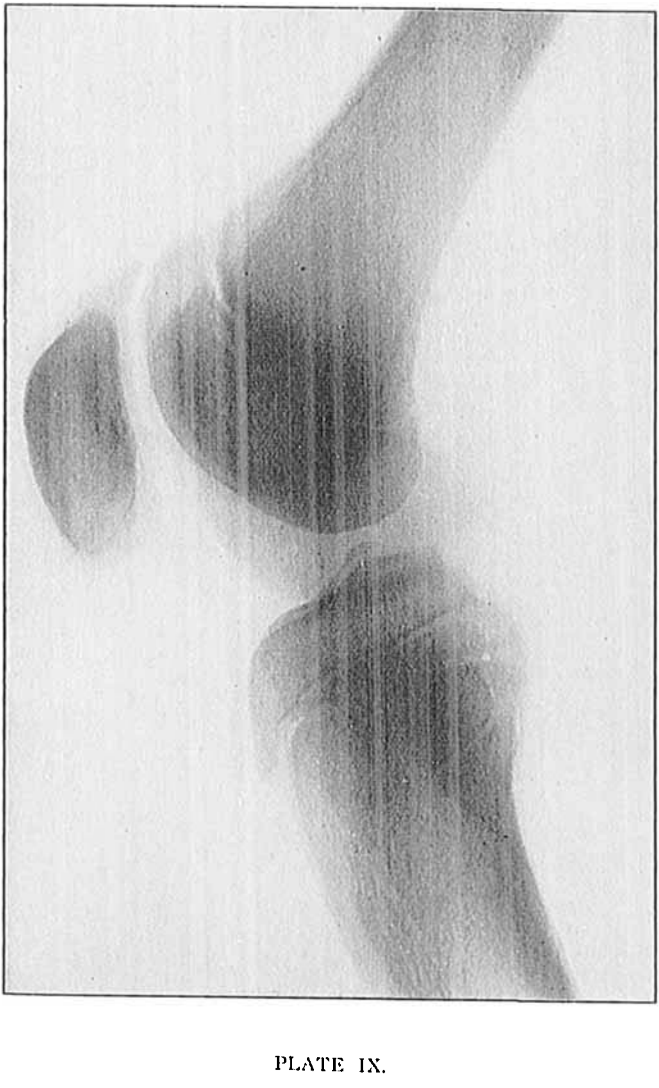

PLATE IX.

and phalangeal bones begin to ossify at the eighth week. The centres for the epiphyses of the metacarpals appear about the third year and unite about the twentieth, while the centres of the epiphyses of the phalangeal bones appear between the third and the fifth years and unite between the eighteenth and the twentieth years. Viewing the entire hand, it is evident that the so-called metacarpal bone of the thumb is a first phalangeal bone from a developmental point of view.

HIP.

The femur develops from five centres,—one for the shaft, appearing about the fifth week, one for the head of the bone, at the end of the first year, one for the greater trochanter, at the fourth year, one for the lesser trochanter, about the thirteenth or fourteenth year, and one for the lower extremity, which appears at the ninth month of fœtal life. These join the shaft by bony union inversely as their ossific centres appear, the upper epiphysis about the eighteenth year, and the lower about the twentieth. For a very complete description of the development of the femur, I must again refer the reader to Poland's work, and I shall quote from him sufficiently to help understand clearly the skiagraphic findings.

"The epiphysis of the head of the femur is developed from a single ossific centre appearing just about its centre,—that is, above and somewhat behind the attachment of the round ligament,—from the tenth to twelfth month after birth. This centre is often surrounded by a number of small osseous granules, especially at its upper part. The cartilaginous head is still connected at this period with the great trochanter by a thick layer or mass of cartilage. This layer or strip at the end of the second year is thin and hollowed out, and presents many small depressions caused by the upward extension and increase in size of the osseous shaft to form the neck of the bone. It is all that remains now of the original cartilaginous upper end of the femur, from which the head and great and lesser trochanters are developed. These are gradually separated away from each other by the growing neck, and subsequently increase in size quite independently of each other. The head passes upward and inward from the growth of the neck in that direction, whilst the great trochanter continues in the direction of the shaft. At this time, the end of the second year, the cartilaginous lesser trochanter is already widely separated from the other two cartilaginous epiphyses. By the end of the fourth year nearly the whole of the epiphysis of the head is osseous, and separated from the great trochanter. . . . . At the seventeenth year the epiphysis is entirely ossified, and appears about to join to the neck, but this is not finally accomplished until the nineteenth to twentieth year." [17]

The hip is the most difficult joint to X-ray properly, and tests to its utmost the efficiency of the apparatus and the skill of the operator. In the first place, it is difficult to get the bone close to the plate, and therefore to get sharp outlines; and, secondly, unless the vacuum in the tube is high and the X-ray penetration is great, it is difficult to overcome the density of the heavy muscles surrounding the joint, for the combined density of the muscle is almost as great as the density of the bone itself.

PLATE X.

Skiagraph of ankle from behind, coronal view, showing lower epiphyses of tibia and fibula, with the astragalus.

Outer edge of tibia seen through the fibula.

Exposure, three minutes.

The position which gives the best result is with the greater trochanter as close to the plate as possible. To accomplish this, the subject must lean slightly to the side skiagraphed and with the foot everted. This position is made more comfortable for the patient by drawing the thigh away from the middle line. It is important that the line of greatest X-ray intensity from the platinum reflector should be directly over the head of the bone.

The skiagraph presented is a fairly good one, and all the important features are brought out. Here, again, the negative is superior to the print. The small ossific centre for the lesser

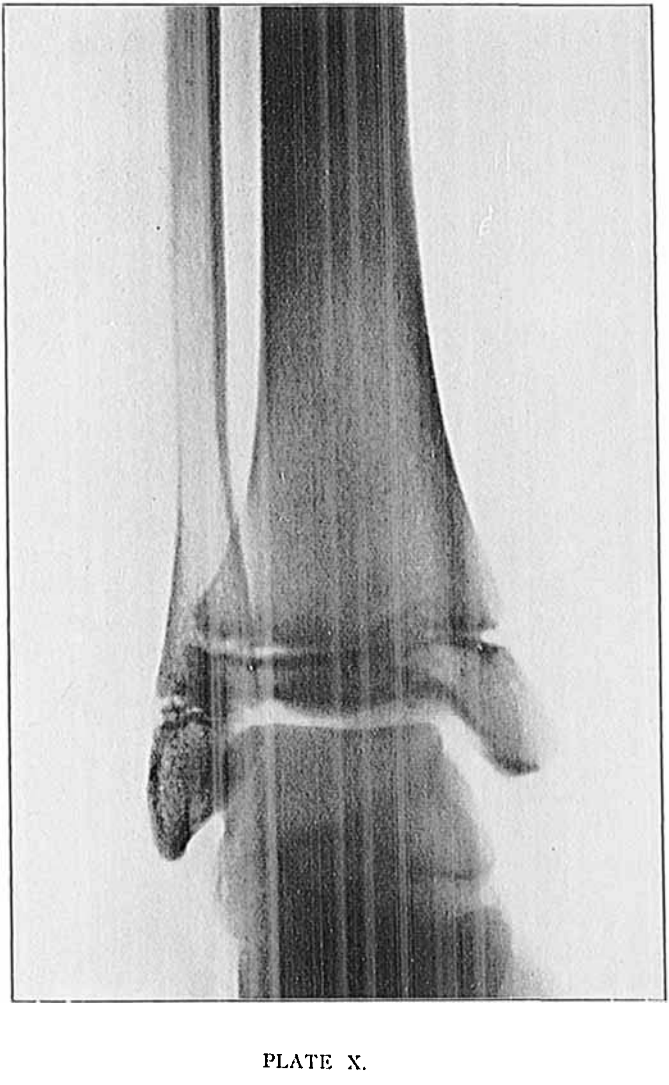

PLATE X.

trochanter is very distinct, somewhat in advance of the time specified by the books.

The great trochanter, by this time well ossified, is very distinct, with its epiphysial line separating it from the shaft. When the hip is taken with the subject lying flat on the plate, the foot being straight, this tuberosity comes out in profile, and its relations to the shaft are better seen. In this position, however, the head of the bone does not come out so well. When so taken, the line of greatest X-ray intensity should come more from the middle line of the body. This will bring out the epiphysis of the lesser trochanter and make the acetabulum more distinct.

The head of the bone is shown well ossified, and there is visible the epiphysial line separating the head from the neck, much better seen in the negative, however. The acetabulum is well differentiated, and the epiphysial line separating the ischium and pubis from the ilium.

KNEE.

The knee-joint is a much simpler joint to understand, both from an anatomical and developmental stand-point. The lower epiphysis of the femur is the only one whose ossification begins before birth.[18]

Ossification advances rapidly, and there is soon formed a large and prominent epiphysis easily studied both in its anatomical and surgical bearings.

"At the sixteenth year this enormous epiphysis is separated by its cartilaginous lamina from the diaphysis, the extremity of which presents a mammillated rounded surface divided by a slight furrow, running in an antero-posterior direction and corresponding to the intercondyloid notch.

"The upper surface of the epiphysis is cup-shaped, with a central projection formed by the median centre of ossification and fitting into the furrow just mentioned on the diaphysis. Its anterior lip projects upward, overlapping the front of the diaphysis, and, like the articular surface, which it includes, projects higher on the outer portion. The cartilaginous line of junction is at the outer portion of the anterior lip about one-eighth of an inch above the articular surface, and slopes downward towards the lateral aspect of the condyles, and thus presents a sinuous outline; behind it reaches the articular surface on each condyle and corresponds between these with the upper limit of the intercondyloid notch. The epiphysis is therefore seen to include the whole of the articular surface, both front and back." [10]

In the frontal view the X-ray well illustrates this description; the entire sinuous epiphysial line with the condyles and intercondyloid notch are all distinct.

According to the usual law, though the first to ossify, it is the last to join the shaft, uniting from the twentieth to the twenty-fifth year. At the age of thirteen it is seen to be fully formed, the largest epiphysis in the body, firmly united still by cartilage to the shaft, and requiring undoubtedly great force to separate it. The frontal view is best taken from behind, and the sagittal view from the inner side. This latter gives us the relation of the patella to the epiphysis and to the joint. By using a celluloid film, which can be adapted to the curved surface of the joint, we get a very striking though distorted skiagraph which brings out prominently the sinuous epiphysial line and the condyles. The condyles and intercondyloid notch are almost as distinct as in a drawing.

PLATE XI.

Skiagraph of ankle from the inner side, sagittal view, showing lower epiphyses of tibia and fibula, and the epiphysis of the os calcis.

The astragalus, the cuboid, the scaphoid, and the cuneiform are distinct with their internal structure.

Sagittal view of the proximal epiphyses of the metatarsals.

Exposure, three minutes.

In the sagittal view the condyle away from the plate is but a faint though sharp shadow, be it noted; a striking example of the distortion produced by the different distances of the different points of an object from the plate. The condyle next to the plate is sufficiently close to give us practically the

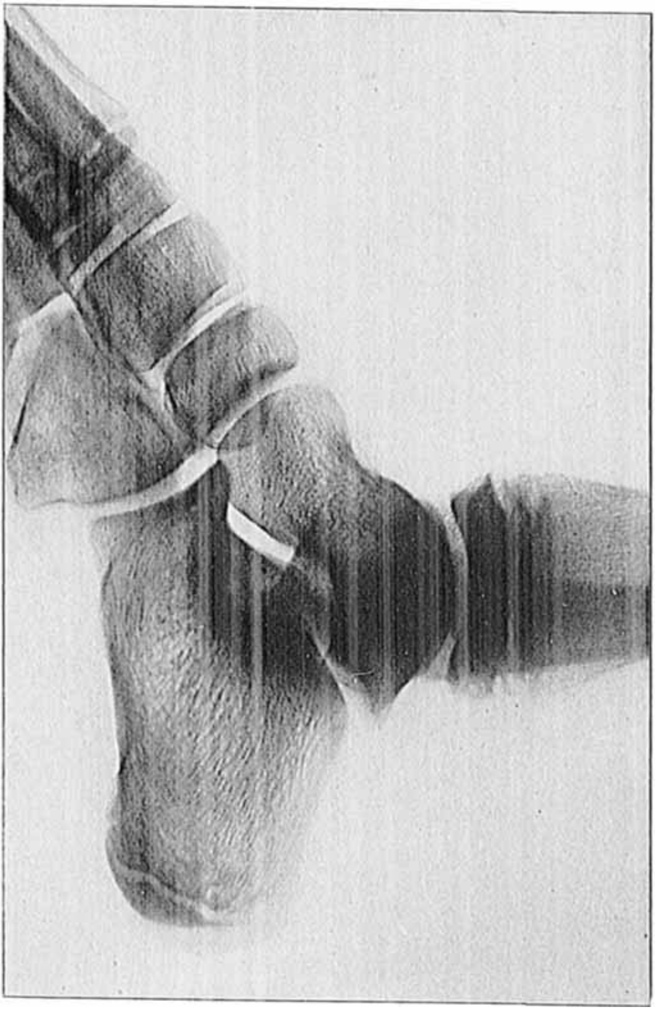

PLATE XI.

exact size of the bone. In the frontal view taken from behind, the bone is not so close to the plate and the shadow is somewhat larger. The bone can be brought somewhat closer to the plate anteriorly, but the patella must be pushed to one side, and the bones are somewhat at an angle. The patella appears as a faint shadow. A good deal of the texture of the bone can be brought out.

The upper epiphysis of the tibia is cartilaginous at birth, but a centre of ossification appears any time from two weeks up to the twelfth month. Gray places it at birth; as already mentioned, it may appear even before birth. The expanded epiphysis with its tuberosities rapidly ossifies. The tubercle of the tibia is an extension downward of the epiphysis. According to Béclard and Sappey, it is often ossified by a separate centre, as in the lower animals.[20]

In the negative of the sagittal view the tubercle is seen as a separate ossific centre; the bony growth downward from the epiphysis is also plainly seen, indicating that the two centres grow towards each other. The strong ligamentum patellæ is also very distinct. Unfortunately, in the printing, an exposure sufficient to bring out strongly these finer details over-exposes the rest of the print. This is the most difficult thing to overcome in printing from highly intensified negatives; certain fine points have to be sacrificed in bringing out the details in the body of the bone. By the fourteenth or fifteenth year this epiphysis is practically completely ossified. According to Gray, it joins the shaft about the twentieth year; according to Poland, from the twentieth to the twenty-second year, and even as late as the twenty-third year.[21]

The X-ray findings are best seen in the frontal view; the upper articular surface with its spinous process and tubercle on each side being beautifully shown. The epiphysial line is much more distinct than in the femur. In the sagittal view, the epiphysial junction not being in line with the X-ray, gives the appearance of two epiphysial lines. Of course, the frontal view dispels this seeming aberration. In the negative all the parts are most beautifully shown. In the print we get a faint indication of the growth downward from the epiphysis to form the tubercle of the tibia. In the frontal section we can see only the base of this process with its characteristic beak.

The upper epiphysis of the fibula is cartilaginous at birth, and it is only four or four and a half years later that the first osseous granules appear, forming a distinct centre between the fifth and sixth year (Poland). According to Gray, this centre appears about the fourth year, uniting with the shaft about the twenty-fifth year. Bland writes, "This epiphysis joins the diaphysis about the twentieth to the twenty-second year; its union may be delayed as late as the twenty-fifth year."[22]

By the X-ray this epiphysis is best seen in the frontal view. At the age of thirteen it is already well ossified, although it is evidently still immature. There is no styloid process, there are no sharp bony outlines, and no close contact with the tibia. In one skiagraph taken the epiphysis appeared entirely free from the tibia, and even in this plate the two bones but just touch. In the sagittal view it is seen through the tibia apparently, the outlines being very distinct in the negative, less so in the plate. In a light print it is of course better seen.

PLATE XII.

Skiagraph of foot from the anterior surface, coronal view, showing the epiphyses of all the bones of the toes.

The scaphoid, cuboid, and three cuneiform bones of the tarsus.

Exposure, two minutes.

ANKLE.

The ankle-joint offers to the X-ray no difficulties in shadowing its component parts. We get a very striking picture of its two epiphyses in a frontal view, taken with the plate on the anterior surface, the foot being extended to its full limit. You get about as good results posteriorly, the tendo Achillis resting on the plate. In the sagittal view, while the composite shadow of tibia and fibula is clear enough, the epiphyses are not so strikingly shown, but the

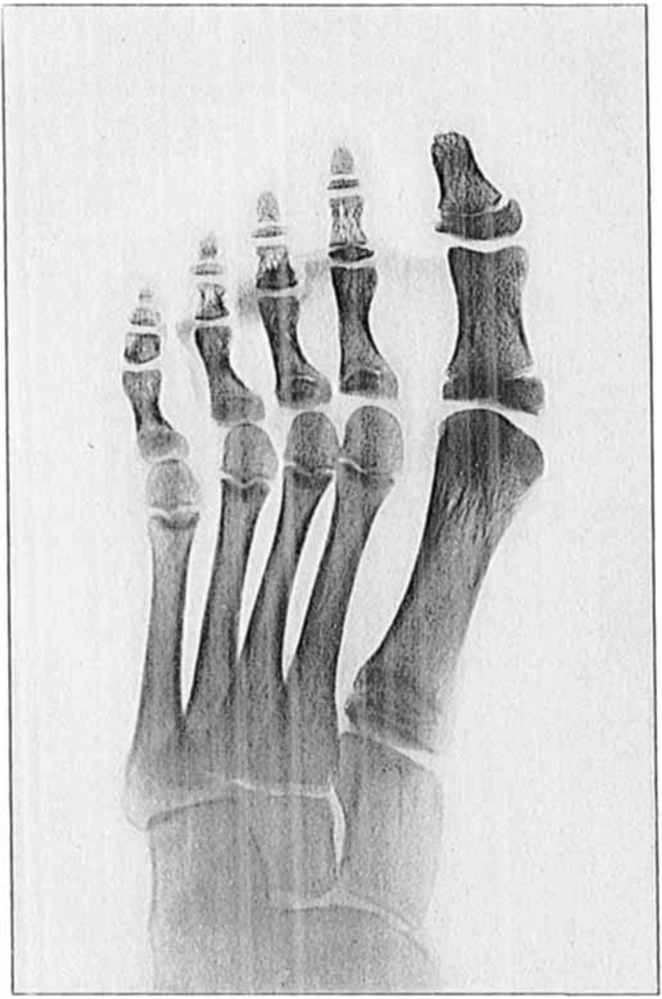

PLATE XII.

ankle, as a whole, is better seen, and at the same time we get the os calcis with its epiphysis.

The lower epiphysis of the tibia appears about the eighteenth month; it ossifies rapidly, the ossification extending into the malleolus by the end of the second year. By the fourteenth or fifteenth year the epiphysis is completely ossified. It unites to the shaft at the eighteenth or nineteenth year (Poland).

Béclard has described one case seen by him where there was a special centre for this malleolus, evidently a very rare occurrence.

In the skiagraph, frontal view, the two epiphyses are beautifully shown; the epiphysial lines very distinct, the cartilages being still quite thick, and the two malleoli well advanced in ossification. The tibia, showing through the delicate fibula where they overlap, gives a striking appearance to the picture. You see here, too, the exact relationship of these two bones to the astragalus. In the sagittal view, the epiphysis of the tibia comes out better than that of the fibula. The thick astragalus having to be reckoned with, the composite shadow is not so translucent.

The centre of ossification of the lower epiphysis of the fibula seems to vary greatly in the time of its appearance; according to Poland, any time from the eighteenth month to the end of the third year. It is completely ossified by the eighth or ninth year, and joins the shaft from the nineteenth to the twenty-second year. This epiphysis appears before the upper one, though the nutrient artery runs downward, being thus an exception to the rule. It, however, follows the rule by uniting first to the shaft.

In the skiagraph two points are very noticeable and worthy of mention, the fibular malleolus is larger than the tibial, and is much lower. Mr. J. Bland Sutton has called attention to the fact that this malleolus extends lower in man than in the higher mammals. Man's erect position must explain this, the malleolus helping greatly to strengthen the ankle.

FOOT.

According to Gray, the epiphysis of the os calcis appears about the tenth year and unites after puberty. It is completely ossified by the thirteenth or fourteenth year.

In the skiagraph it is evidently well ossified, forming a very characteristic cap to the bone. It is best brought out when skiagraphed from the inner side. The spongy texture of the tarsal bones is beautifully brought out, being especially fine in the negative.

The foot offers the same fascination for X-ray work as the hand on account of the sharp and minute details brought out. Here the print does more justice to the negative, and with a magnifying-glass we can marvel at the microscopic details which the X-ray reveals. Through the magnifier we get something of a stereoscopic effect, the shadow and the substance in one.

The osseous centres for the shafts of the metatarsal and phalangeal bones appear from the seventh week to the second and even to the fourth month. The centre for the proximal epiphysis of the metatarsal of the big toe appears about the fifth year. The centres for the distal epiphyses of the remaining metatarsals appear about the third year. The centres for the phalangeal epiphyses appear from the fourth to the sixth and even to the seventh year. They all unite from the seventeenth to the twentieth year.

The skiagraph speaks for itself; it was taken from the anterior surface. It could well replace the diagram given in Gray to show the schema of the development of the foot.

It is noticeable that in the terminal phalangeal bones of the four smaller toes the epiphyses are almost as large as the bones themselves, while in the little toe the epiphysis is actually larger than the terminal bone. Again, in the second phalangeal row the bone for the little toe and that for the toe next to it have apparently no epiphyses.

The two sesamoid bones of the big toe are seen as dark shadows through the head of the metatarsal bone. They are at this age well developed.

REFERENCES.

[1] "An X-Ray Study of the Normal Movements of the Carpal Bones and Wrist." Reprinted from Proceedings of the Association of American Anatomists, 1898.

[2] "Traumatic Separation of the Epiphyses." By John Poland, F.R.C.S., with 337 illustrations and skiagrams. London: Smith, Elder & Co., 15 Waterloo Place. 1898. Pp. xxxi-926.

[3] I have just had brought to my notice a paper in the *Deutsche Zeitschrift für Chirurgie*, for January, 1900, by Dr. Oscar Wolff, entitled, "Ueber traumatische Epiphysenlösungen," which is a model of scientific excellence and is well worthy of careful study. The many skiagraphs illustrating it have been made diagrammatic to bring out the salient features.

[4] Op. cit., page 157.
[5] Op. cit., page 163.
[6] Op. cit., page 164.
[7] Op. cit., page 262.
[8] Op. cit., page 263.
[9] Op. cit., page 264.
[10] Op. cit., page 266.
[11] Poland, op. cit., page 457.
[12] Op cit., page 458.
[13] Op. cit., page 471.
[14] Op. cit., page 470.
[15] Op. cit., page 580.
[16] Op. cit., page 478.
[17] Op. cit., pages 615, 616.

[18] Poland states that occasionally an ossific centre appears before birth in the upper epiphysis of the tibia.

[19] Op. cit., page 678.
[20] Poland, op. cit., page 798.
[21] Op. cit., page 799.
[22] Op. cit., page 856.